A True Airspeed Correction Methodology for Aircraft Fuel Consumption Calculations

by Terry Jameson

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Terry Jameson
Computational and Information Sciences Directorate, ARL

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14. ABSTRACT

A methodology is described to derive corrected True Airspeed (TAS) values for inclusion in fuel consumption calculations for Unmanned Aircraft Systems (UAS). Earlier work to develop a UAS Fuel Consumption Algorithm (FCA) relied upon default TAS values that are published in the aircraft's operations manual. Use of a default TAS in the FCA can result in fuel consumption estimations that are in error by as much as 10–20%. The TAS calculations described herein incorporate meteorological parameters that can be obtained via standard on-board instruments that are readily-available to the UAS mission commander. The step-by-step process to derive corrected TAS is explained in some detail, and a real-world example is included by which the results are verified. It is anticipated that the corrected TAS methodology will eventually be incorporated into the FCA software.

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True Airspeed, Fuel Consumption Algorithm, Virtual Temperature, Atmospheric Density, Ground Speed, Standard Atmosphere, Altimeter Setting

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1. Summary

The U.S. Army Research Laboratory (ARL) Technical Report (TR) ARL-TR-4803 (Jameson, May 2009) describes the development of a prototype fuel consumption algorithm (FCA) that eventually will become a module of the aircraft weather routing tool. In order to properly compute fuel consumption estimates, an accurate true airspeed (TAS) must be input to the FCA. In the FCA's current configuration, the TAS being input is simply a published value that is valid only under standard atmosphere (SA) conditions at sea level. Under almost all potential flight conditions, the atmospheric density is less than the SA sea level value and the actual TAS is correspondingly greater. Standard TAS values published in aircraft operations manuals can be 10–20% in error or more.

A methodology has been developed to compute an aircraft's actual TAS from information at-hand, in order to use the proper value in fuel consumption calculations. The ambient flight altitude air density is required in order to convert the indicated airspeed (IAS) to TAS, and density is derived using air temperature and pressure. While outside air temperature is commonly measured on all manned aircraft and many unmanned aircraft systems (UAS), air pressure is not. The methodology described herein works from other information to derive the pressure value; namely altimeter setting (AS), surface elevation and temperature, and indicated altitude.

2. Introduction

Unmanned Aircraft Systems (UAS) have become a key component of U.S. military operations in theaters abroad, and are finding their place in border patrol and other homeland security missions within the Continental United States (CONUS). UAS are likely to have an increasing role in reconnaissance, surveillance, communication and weapons delivery.

The U.S. Army Research Laboratory, Battlefield Environment Division (ARL, BED) has been developing an aviation impact routing tool (AIR) to address the issue of weather impacts upon various UAS missions. The AIR depicts regions of adverse weather impacts (on a map background display) and then searches for alternate routes to target areas and return that minimize those impacts.

A related factor that is to be included in AIR involves UAS fuel consumption. Fuel consumption rates, remaining fuel quantity, and, therefore, allowable time on-target are vital issues that must be considered to safely and most effectively employ UAS in their various mission roles. In particular, as AIR proposes alternate routes that minimize adverse weather effects, additional

fuel requirements to fly those routes must be taken into account. A recent ARL Technical Report (TR) (Jameson, May 2009) describes the development of a prototype Fuel Consumption Algorithm (FCA) that addresses these issues. The prototype FCA is being designed such that minimal operator input is required, while a maximum amount of pertinent flight information is produced. UAS flight performance characteristics, prevailing winds, and mission route definitions are incorporated into the FCA. Using these data, the algorithm computes ground speeds along the various mission segments (and therefore flying times), fuel consumed, and then fuel/time available to be expended at a target area. It is hoped that the FCA will ultimately prove to be a valuable decision aid for UAS mission commanders.

This Technical Note describes the development of a correction factor to be applied to one of the inputs to the FCA, the True Airspeed (TAS), enabling more accurate computations of UAS fuel expenditures and mission flight times.

3. Definitions and Background

3.1 Definitions

1. TAS: As referred to in this document, TAS is defined as: "True airspeed is the vector difference of the velocity vectors of the aircraft and the air mass, both with reference to the earth's surface. When determining the true airspeed of an aircraft under zero wind conditions and in horizontal flight, the true airspeed of the aircraft is equal to the speed of the aircraft relative to the earth's surface. When determining the true airspeed of an aircraft under non-zero wind conditions an estimation of the wind speed vector is used." (Wikipedia,[a] 23 September 2009) TAS is a function of the thrust being developed by the aircraft's engine(s)/propeller(s) and (in an opposing sense) of the amount of drag created by its airframe.

2. Station Pressure (P_{stn}): The ambient air pressure measured by a "barometer" at a surface weather station. P_{stn} varies on a diurnal basis as the temperature varies, and is also influenced by the passage of high and low pressure weather systems. The units of measure of P_{stn} are the hecto-Pascal (hPa) or inches of mercury (inHg). (1.0 inHg = 33.86 hPa).

3. Air Density (AD): The relative "thickness" of the air, that is a function of air temperature, pressure, and (to a limited extent) moisture content. The unit of measure of "AD" herein is kilogram per cubic meter (kg/m^3). As air pressure increases with constant temperature, AD *increases*; as air temperature increases with constant pressure, air density *decreases*.

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[a] Wikipedia, The Free Encyclopedia is an on-line encyclopedia.

4. Virtual Temperature (T_{virt}): Although it might be counter-intuitive, the moister the air is, the *less dense* it is.[b] T_{virt} is used in air density calculations as a means of compensating for the effects of moisture. T_{virt} is a fictitious temperature that cannot be measured, but rather is computed given the measured temperature and moisture content of the air. T_{virt} is always equal to or slightly greater than the measured air temperature, being equal when the moisture content is zero and increasing as moisture content increases. As moisture content increases, T_{virt} diverges above the ambient temperature and when used to compute density, the resulting density value decreases accordingly. The method of computing T_{virt} will be described in a later section.

5. Moisture Content and Relative Humidity (RH): The "moisture content" of the air refers to the amount of water vapor (water in the invisible, gaseous state) that is present. As mentioned earlier, the moisture content of the air affects its density (with increasing amounts actually *decreasing* the density value). There are several adequate measures of moisture content; the measure that will be employed herein is the RH. The value of RH varies from 0% (no water vapor present) to 100% (the maximum amount of water vapor for a given temperature is present).

6. Sea level Pressure (P_{sl}): The air pressure assumed to exist at sea level, given an actual air pressure measured at some other altitude. This is computed from the $P_{stn,}$ the altitude of the weather station where it is measured, and some estimate of the average temperature over the layer between the station altitude and sea level. P_{sl} is a reference pressure from which altitude measurements are derived.

7. Standard Atmosphere (SA): "The U.S. SA, a series of models that give values for pressure, density, and temperature over a range of altitudes." (Wikipedia, 23 September 2009.)

There are several SA parameters that are pertinent to this study.

At sea level the SA:

    a. Air pressure=1013.25 hPa;

    b. Temperature=15 °C, 288 Kelvin;

    c. Relative Humidity=0%;

    d. Density=1.225 kg/m^3

The SA Temperature Lapse Rate (the rate at which temperature is assumed to decrease with increasing altitude) is: 6.5 C/km

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[b] For reasons that are not pertinent to this study.

8. IAS: "Aircraft display an indicated airspeed on an instrument called an airspeed indicator. Indicated airspeed will differ from true airspeed whenever the aircraft is flying in air whose density differs from the density at sea level and 15 °C. Indicated airspeed is used in aircraft operations as the aircraft stalling speed and structural limiting speeds are dependent on indicated airspeed, irrespective of true airspeed. However, proper navigation via dead reckoning (without constant ground reference) requires the use of true airspeed and wind corrections." (Wikipedia, 23 September 2009.)

9. Ground Speed (GS): A quantity depicting the speed at which the aircraft is traveling in relation to the ground below. The GS is the critical value that ultimately must be determined in order to accurately compute the time required to fly each mission leg (and, therefore, the fuel expended).

10. Altimeter: An instrument on-board an aircraft that measures altitude above a reference pressure level (such as the calculated sea level pressure). An altimeter is actually a barometer, but its display is not in units of pressure but rather in units of height above the reference pressure level. An altimeter is mechanically geared to measure height assuming a pressure variation with height according to the SA.

11. AS: "The value of atmospheric pressure to which the scale of an aneroid altimeter is set; after United States practice, the pressure that will indicate airport elevation when the altimeter is 10 feet (3 meters) above the runway (approximately cockpit height)." (Wikipedia, 29 September 2009.)

Thus the AS is a pressure value that the pilot dials in to a window on the face of the altimeter; more specifically, it is the reference pressure from which the altimeter will measure and indicate its altitude. The AS is a *fictitious* pressure, in that it is a pressure value not measured, but rather, computed from the ambient air pressure at an airfield (P_{sfc}),[c] and is a pressure that is *assumed* would exist if a hole could be dug from the airfield down to sea level and a barometer placed at the bottom of the hole. This is the same as P_{sl} except it is given in inches of mercury (in_{Hg}) and computed from the surface temperature rather than an average temperature. The AS is also assumed to be applicable for aircraft flying in the general vicinity of the airfield from which it is computed and it is updated periodically as P_{sfc} changes.

12. Flight Altitude (FA) Temperature (T_{fa}) and Pressure (P_{fa}): Both temperature and pressure are required for density calculations. Most aircraft have an outside air temperature (OAT) gauge from which the pilot can obtain the T_{fa}. However, aircraft do not have a means of directly measuring P_{fa}, and it must be computed from other known parameters, as will be described later.

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c The method of computing the AS from the ambient pressure will be described in a later section.

13. MATLAB: The MATrix LABoratory programming language. The prototype FCA and its subprograms (including the subprogram being described herein to determine the correct TAS) were developed in MATLAB.

3.2 Background

One of the required inputs to the FCA is the aircraft's TAS. As described in ARL-TR-4803 and in section 3.1.1., the TAS vector is used as one component of a vector triangle, along with the wind vector, to solve for the third vector that is the aircraft's GS. It is the GS that must be accurately determined in order to correctly calculate the time of flight and therefore the fuel consumed over the course legs of a mission. To date, the TAS used in the FCA has simply been a default value as is typically published in any aircraft's flight operations manual.[d] However, as will be further explained below, under most flight conditions the default TAS value is typically too low. A methodology is described herein to correct the TAS in order to more accurately compute fuel consumption estimates.

As explained in the definitions, it is the IAS that is measured by the aircraft's airspeed indicator. In almost all flight conditions, the IAS is *not* equivalent to the TAS. The airspeed indicator instrument responds to the differential between the dynamic pressure of the ram air entering the aircraft's pitot tube (a tube-shaped aperture extending from the leading edge of the wing) and the still-air within the aircraft's static pressure system. It is mechanically geared to read correctly (to correctly indicate the TAS) only when the ambient air is at sea level with the SA density (1.225 kg/m^3). At flight levels above sea level, where in most cases the air is less dense,[e] the dynamic air pressure is reduced and the airspeed indicator reads too low (the IAS is lower than the TAS). For some UAS and typical flight altitudes in the battlefield, the IAS could be as much as 10–20% in error. Also, the published, default value of the TAS could be in error by the same magnitude.

The solution to the problem of an inaccurate TAS in the FCA is to replace its default value with its actual value by correcting the IAS for the ambient air density conditions.

4. Approach

Several steps must be taken before the correct TAS can be determined. Those are:

1. Determine the atmospheric pressure at the FA of the UAS.

2. Determine T_{virt} at the FA.

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[d] It is a value that is only applicable under SA conditions at sea level.

[e] With very cold temperatures, even at altitudes somewhat above sea level, the air might actually be denser than under standard sea level conditions. For most UAS flight conditions, however, this would not be the case.

3. Utilize the atmospheric pressure and T_{virt} to determine the AD at the FA.

4. Apply the AD as a correction factor to the IAS to determine the TAS.

5. Constants and Conversion Factors

The following is a list of constants and conversion factors that are required in various equations relating to TAS computations. (These constants and conversion factors were obtained primarily from (Hess, 1959; List, 1971).

mv	= 18.016	[molecular weight of water vapor (gm/mole)]
md	= 28.988	[molecular weight of dry air (gm/mole)]
eps	= 0.6215	["epsilon" - ratio of mv/md]
Le	= 597.3	[Latent heat of vaporization (cal/gm)]
Rstar	= 1.98624	[Universal gas constant (cal/mole-Kelvins)]
T_{sa0}	= 288.16	[SA sea level temperature (Kelvins)]
P_{sa0}	= 1013.25	[SA sea level pressure (hPa)]
D_{sa0}	= 1.225	[SA sea level density (kg/m^3)]
E_{so}	= 6.112	[Saturation vapor pressure @ 0°C (hPa)]
a0	= -0.03414	[Constant required for the pressure equation]
a1	= 0.190284	[Constant required for the altimetry equation]
a2	= 5.255	[Inverse of "a1", also for the altimetry equation]
a3	= 8.4423 x 10^{-5}	[Third constant required for altimetry equation]
L	= 6.5 x 10^{-3}	[Temperature lapse rate in the SA (°C/m)]
R	= 287.3	[gas constant for dry air (ergs/gm-Kelvins)]
inHg_hPa	= 33.86	[Conversion factor inches Hg to hPa]
ft_meters	= 0.3048	[Conversion factor feet to meters]
C_K	= 273.16	[Conversion from °C to Kelvins]
den_fac	= 0.34838	[Conversion factor in density equation]

6. P_{fa} Calculation

Presently there is no direct way of measuring the ambient air pressure given the instruments on-board either manned aircraft or UAS; and yet, a value for the pressure at flight altitude (P_{fa}) is

required in order to compute air density and subsequently apply a correction factor to the IAS to obtain TAS.   Two parameters that are available from most aircraft's instrumentation are AS and OAT. Given these values, a two-step process can be followed in order to compute the P_{fa}.[f]

1. According to a National Weather Service (NWS) Web site (NWS, 29 November 2010) the following equation can be used to compute the AS at an airfield location given a barometer-measured air pressure value ($P_{sfc,}$ in units of hPa) and the known elevation of the airfield above SL ($Z_{sfc,}$ in units of meters):

$$AS = P_{sfc} \times \left[1 + \left(\left(\frac{1013.25^{.190284} \times .0065}{288}\right) \times \left(\frac{Z_{sfc}}{P_{sfc}^{.190284}}\right)\right)\right]^{5.255} \tag{1}$$

For the purposes of this study, two of the parameters in equation (1) are known (AS and Z_{sfc}) and therefore it must be solved for P_{sfc}.

First, substituting some of the variable names for the constants:

$$AS = P_{sfc} \times \left[1 + \left(\left(\frac{P_{sa_0}^{a1} \times L}{T_{sa_0}}\right) \times \left(\frac{Z_{sfc}}{P_{sfc}^{a1}}\right)\right)\right]^{a2}$$

Next, solving for "a3" in one of the terms in parentheses, and substituting:

$$\left(\frac{P_{sa_0}^{a1} \times L}{T_{sa_0}}\right) = 8.423 \; X \; 10^{-5} = a3$$

$$AS = P_{sfc} \times \left[1 + \left(a3 \times \left(\frac{Z_{sfc}}{P_{sfc}^{a1}}\right)\right)\right]^{a2}$$

Rearranging to solve for P_{sfc}:

(note that: a1 = 1/a2)

$$AS^{a1} = P_{sfc}^{a1} \times \left[1 + \left(a3 \times \left(\frac{Z_{sfc}}{P_{sfc}^{a1}}\right)\right)\right]$$

$$AS^{a1} = P_{sfc}^{a1} + \left(a3 \times Z_{sfc}\right)$$

$$P_{sfc}^{a1} = AS^{a1} - \left(a3 \times Z_{sfc}\right)$$

$$P_{sfc} = \left[AS^{a1} - \left(a3 \times Z_{sfc}\right)\right]^{a2} \tag{2}$$

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[f] If in the future Met data instruments that directly measure P_{fa} are employed on UAS, the two-step process described in section 6 will not be necessary.

2. Given P_{sfc} found by equation (2), a second equation may be used to extrapolate pressure from the surface up to the FA and find P_{fa}. It is (Hess, 1959):

$$\left(Z_{fa} - Z_{sfc}\right) = \frac{-R}{g} \times T_{bar} \times \log_e \frac{P_{fa}}{P_{sfc}} \qquad (3)$$

In equation (3), most of the variable names have been changed from those in the text book reference in order to conform to variables listed in this document, but the resulting value remains the same. Unlike equation (2) and the AS equation from which it is derived (which are based upon SA temperature and pressure variations), equation (3) is based upon the mean temperature within a layer of the atmosphere (T_{bar}), or:

$$T_{bar} = \frac{\left(T_{fa.} + T_{sfc}\right)}{2}$$

The quantity ($Z_{fa} - Z_{sfc}$) is the "thickness" of the layer from the surface up to the flight altitude. Since the surface elevation is known, the surface pressure has been determined, the value for Z_{fa} may be read from the altimeter, and a value for T_{bar} can be computed; equation (3) can be rearranged to solve for P_{fa}.

Substituting for $-R/g$, let:

$$\frac{-R}{g} = \frac{1}{a0} = -29.29 \rightarrow a0 = -3.414 \times 10^{-2}$$

$$\left(Z_{fa} - Z_{sfc}\right) = \frac{1}{a0} \times T_{bar} \times \log_e \frac{P_{fa}}{P_{sfc}}$$

Rearranging and solving for P_{fa}:

$$\log_e \left(\frac{P_{fa}}{P_{sfc}}\right) = \frac{a0 \times \left(Z_{fa} - Z_{sfc}\right)}{T_{bar}}$$

$$\frac{P_{fa}}{P_{sfc}} = e^{\left(\frac{a0 \times \left(Z_{fa} - Z_{sfc}\right)}{T_{bar}}\right)}$$

$$P_{fa} = P_{sfc} \times e^{\left(\frac{a0 \times \left(Z_{fa} - Z_{sfc}\right)}{T_{bar}}\right)} \qquad (4)$$

7. T_{virt} Calculation

The effects of pressure and temperature upon density are significantly greater than that of moisture content; and, aircraft currently have no means of measuring moisture content (including RH). However, it is expected that in the relatively near future meteorological (Met) instrumentation packages may be installed on some UAS that are engaged in battlefield missions as well as in homeland security operations that will be measuring RH. Consequently, the issue of the effect of moisture content upon density will be addressed in this study. To do so, the method of computing Virtual Temperature is described below:

A. Find the Saturation Vapor Pressure ($E_s\_T_{fa}$) at the temperature at flight altitude:

Applicable equation:

$$\log_e \left(\frac{E_s\_T_{fa}}{E_{s0}}\right) = \left(\frac{mv \times Le}{Rstar}\right) \times \left(\frac{1}{273} - \frac{1}{T_{fa}}\right) \text{ (Hess, 1959)}$$

Let:

$$\text{expo} = \left(\frac{mv \times Le}{Rstar}\right) \times \left(\frac{1}{273} - \frac{1}{T_{fa}}\right)$$

Use T_{fa} and solve to find the value of "expo". Substitute in "expo".

$$\log_e \left(\frac{E_s\_T_{fa}}{E_{s0}}\right) = expo$$

Solve for the Saturation Vapor Pressure

$$\left(\frac{E_s\_T_{fa}}{E_{s0}}\right) = e^{expo}$$

$$E_s\_T_{fa} = E_{s0} \times e^{expo}$$

B. Using $E_s\_T_{fa}$, find the corresponding Saturation Mixing Ratio (ws_T_{fa}): (Hess, 1959)

$$ws\_T_{fa} = \frac{eps \times E_s\_T_{fa}}{(P_{fa} - E_s\_T_{fa})}$$

C. Using ws_T_{fa} and the ambient Relative Humidity (RH as a decimal value), find the ambient Mixing Ratio (w_T_{fa}): (Hess, 1959)

$$w\_T_{fa} = ws\_T_{fa} \times RH$$

D. Using w_T_{fa} find the value for T_{virt} (Hess, 1959):

$$T_{virt} = T_{fa} \times \left[\frac{(1 + w\_T_{fa}/eps)}{(1 + w\_T_{fa})}\right] \tag{5}$$

8. Density and TAS Calculation

Find the ambient density at the flight altitude: (List, 1971)

$$D_{fa} = den_{fac} \times \left(\frac{P_{fa}}{T_{virt}}\right) \tag{6}$$

Using the ambient density, the SA sea level Density, and the IAS, find the TAS: (Wikipedia, 23 September 2009)

$$TAS = IAS \times \sqrt{\frac{D_{sao}}{D_{fa}}} \tag{7}$$

9. Example TAS Calculation

9.1 Assumptions

An example TAS calculation will require that the following assumptions be made:

(1) <u>The altitude that a standard altimeter would have read during a flight on the case-study day can be computed from a variation of equation (2).</u>

Equation 2 incorporates a known ambient pressure value (the surface pressure in this case) and a known elevation above sea level (surveyed for the airport location) and is used to derive the AS. For the purposes of this example, the equation will be rearranged such that the *known AS* and a known flight altitude pressure (see the following paragraph) will be incorporated to derive the altitude reading given by the instrument.

(2) <u>The UAS is flying at an altitude where the actual ambient pressure is already known to be 700 hPa.</u>

This pressure is being measured within the altimeter and converted to altitude by the instrument (according to the variation of equation (2) that is derived in 9.2 below). However, this pressure is currently not known to the pilot/mission commander of the UAS.

9.2 Altimeter equation derivation

For the purposes of this example only, the following derivation is necessary to determine what altitude an altimeter *would have been* reading had the aircraft been flying at a pressure level of 700 hPa. Beginning with equation (2):

$$P_{sfc} = \left[AS^{a1} - \left(a3 \times Z_{sfc} \right) \right]^{a2}$$

Replace P_{sfc} with P_{fa} and Z_{sfc} with Z_{fa}.

$$P_{fa} = \left[AS^{a1} - \left(a3 \times Z_{fa} \right) \right]^{a2}$$

Rearrange to solve for Z_{fa}:

$$P_{fa}^{a1} = \left[AS^{a1} - \left(a3 \times Z_{fa} \right) \right]$$

$$AS^{a1} - P_{fa}^{a1} = a3 \times Z_{fa}$$

$$Z_{fa} = \frac{\left(AS^{a1} - P_{fa}^{a1} \right)}{a3} \tag{8}$$

9.3 Input Data

The following input datum was valid at 0500 Mountain Standard Time (MST) [g], 25 January 2010, at the 700 hPa pressure level (i.e., $P_{fa} = 700$ hPa) above the Santa Teresa, NM, NWS observation site (EPZ), approximately 32 km west-northwest of the El Paso, TX, airport (ELP).

   Temperature at 700 hPa ($T_{700} = T_{fa}$):   +1.0 °C

It is assumed herein that the temperature at 700 hPa remained constant for 9 hours, until 1400 MST.

The following input data were valid at 1400 MST, 25 January 2010, derived from the automated weather observing site at ELP. The elevation Above sea level (ASL) of ELP is 3952 ft. (1205 m ASL).

- Temperature at the surface (T_{sfc}): +9.4 °C

- AS: 1016.5 hPa (30.02 in Hg)

Other required input data.
- RH at flight altitude (two samples):   0% and 100%

- IAS:............................100 kts

Applying equation (8), the following value was obtained for the estimated indicated altitude:

Z_{fa}: 9941 ft. ASL

9.4   TAS Computation

Using the input data from section 9.3, the following values were obtained from the TAS MATLAB code:

- TAS (100 % RH): ......117.3 kts

- TAS (0% RH): ....117.1 kts

The difference of 0.2 kts between the TAS values is consistent with effect of moisture on air density. As explained in section 3.2, the more humid the air becomes, the less dense it is and the greater the difference between the IAS (100 kts) and the TAS. Obviously, the effect of RH on TAS computations is minimal and could probably be neglected entirely. However, since it is anticipated that an RH value may be measured by instruments on-board UAS in the future, it is being incorporated into these computations.

An on-line TAS calculator that is used by general aviation pilots was accessed to compare against the results obtained above (Paragon, 2009). The required input was:

- Indicated Altitude: ....9941 ft. ASL

- Altimeter Setting:..30.02 in Hg

- Outside Air Temperature: ....+1.0 °C

- IAS:..100 kts

- The resulting TAS from the calculator was:.....117 kts

    In this example then, the output from the TAS algorithm compares closely with the value obtained from the on-line calculator and is assumed to be correct.

10. Conclusion

A methodology is described herein by which the actual TAS value for a UAS can be computed. Use of a more precise TAS (as opposed to simply a default value) in a UAS mission planning system such as the AIR tool (with the FCA implemented) is key in making accurate GS estimates that would be anticipated over the course of a flight (whether during the planning phase or for updates during mission execution). This in turn allows a more realistic accounting to be made of projected fuel expenditures for primary and alternate routes, thus maximizing allowable time on-target for the UAS and enhancing the overall safety of the operations.

TAS values derived using this methodology are based upon prevailing Met conditions, as well as the current aircraft IAS and FA. The required Met and flight parameters (OAT, T_{sfc}, AS, FA, and IAS) are all readily-obtainable during most (if not all) UAS operations. An example is given for which the computed TAS compared almost identically with that found using a commercial Web site. During this research, a number of other TAS computations were compared to the Web site, resulting in a mean difference of less than one knot. In many cases for which realistic Met and flight parameters were input, a TAS value was computed which differed from the IAS by as much as 10-20%. Assuming such variations could also be expected from a default TAS value, errors of a similar magnitude would be projected into GS and fuel consumption computations as well. Implementation of the TAS methodology could greatly reduce or eliminate such errors.

The TAS methodology was originally coded in the MATLAB programming language for testing. It has recently been converted to the Java programming language and is being integrated into the FCA. The FCA/TAS combined algorithm is expected to be incorporated into the AIR planning tool in the near future to allow operational feasibility assessments of the alternate aircraft routes being proposed.

11. References

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List of Symbols, Abbreviations, and Acronyms

AD	air density
AIR	aviation impacts routing tool
ARL	U.S. Army Research Laboratory
AS	altimeter setting
ASL	above sea level
BED	Battlefield Environment Division
CONUS	Continental United States
ELP	El Paso, TX
$E_{s\_}T_{fa}$	saturation vapor pressure at flight altitude temperature
FA	flight altitude
FCA	fuel consumption algorithm
GS	ground speed
hPa	hecto-Pascal
IAS	indicated airspeed
inHg	inches of mercury
kg/m^3	kilogram per cubic meter
MST	Mountain Standard Time
NWS	National Weather Service
OAT	outside air temperature
P_{fa}	pressure at flight altitude
P_{stn}	station pressure
P_{sl}	sea level pressure
RH	relative humidity
SA	standard atmosphere

TAS	true airspeed
T_{fa}	temperature at flight altitude
TR	technical report
T_{sfc}	temperature at the surface
T_{virt}	virtual temperature
UAS	unmanned aircraft systems
UTC	Universal Time Coordinate
w_T_{fa}	ambient mixing ratio at the flight altitude temperature
ws_T_{fa}	saturation mixing ratio at the flight altitude temperature
Z_{fa}	height at flight altitude
Z_{sfc}	surface elevation

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